

Improving on the spatial location of geostationary satellite-derived FRP by accounting for parallax effect

Cristina Ponte Lira^{1,2}, Emanuel Dutra^{1,2}, Weidong Xu^{3,4}, Martin Wooster^{3,4}, Isabel Trigo^{1,2}

¹ Instituto Português do Mar e da Atmosfera, Earth Observation Unite (NOT), Portugal

² Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Portugal

³ King's College London, Leverhulme Centre for Wildfires, Environment and Society, Department of Geography, UK

⁴ NERC National Centre for Earth Observation (NCEO), King's College London, UK

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Abstract

When a satellite observes the Earth at an angle, the apparent position of elevated features, such as mountains, clouds or fires in high terrain, can be shifted from their true ground location. This effect, which may be particularly pronounced in the case of geostationary platforms providing observations under systematically high viewing angles in many places, is known as parallax displacement and becomes larger as terrain elevation and satellite viewing angle increase.

Meteosat satellites operated by EUMETSAT provide frequent near-real-time observations that are essential for wildfire detection and monitoring. The new Meteosat Third Generation (MTG) satellites, equipped with the Flexible Combined Imager (FCI), offer improved spatial, temporal and spectral capabilities compared with previous systems. These improvements support better detection and tracking of active fires.

The LSA SAF Fire Radiative Power product (FRP-PIXEL) provides information on the location, timing and radiative energy of active fires, which can be used as an indicator of fire intensity and biomass consumption. However, standard geostationary processing assumes that observed features are located at sea level. As a result, fires occurring in elevated terrain may be incorrectly geolocated due to parallax displacement.

This work presents an updated MTG FRP-PIXEL product that includes both the original fire and terrain-corrected coordinates. The correction aims to improve the spatial accuracy of active-fire locations, especially in mountainous regions. Preliminary comparisons with active-fire information derived from high-resolution Sentinel-2 imagery show that the correction can improve the location of FRP detections over high-elevation terrain.

1. Introduction

Fire Radiative Power (FRP) measures the energy released by active fires, providing a quantitative estimate of fire intensity and biomass burning (Freeborn et al., 2008). FRP is a fundamental parameter used to characterize and measure active fires from space (Wooster et al., 2021).

FRP can be estimated from satellite images by using the mid-infrared signal, where actively burning vegetation produces a strong thermal anomaly relative to the background land surface (Chen et al., 2024). The physical basis is that the radiative energy emitted by flames and hot combustion zones is proportional to the amount of biomass being consumed. Therefore, FRP can be used as a near-real-time proxy for fire intensity and fuel consumption.

Geostationary satellites observe the same region of the Earth very frequently, typically every 5–15 minutes depending on the sensor and scan mode. This high temporal resolution provides the main advantage over polar-orbiting sensors such as MODIS, VIIRS or Sentinel-3 SLSTR. For FRP, this is especially important because fire behaviour changes rapidly. A polar-orbiting satellite may observe a fire only a few times per day, while a geostationary sensor can better capture the fire growth, peak intensity and decay.

FRP estimates derived from geostationary satellites is widely used for:

- Near-real-time fire monitoring, including detection of active fire fronts and fire intensification (Pletsch et al., 2022).
- Estimating biomass burning emissions, as variables like FRP and FRE can be linked to fuel consumption

and emissions of gases and aerosols (Mota & Wooster, 2018).

- Air quality forecasting, especially for smoke plume modelling and aerosol injection estimates (Kumar et al., 2022).
- Fire danger and fire behaviour analysis, by tracking diurnal fire cycles and rapid changes in intensity (Coskuner et al., 2026; Liu et al., 2024).
- Climate and carbon-cycle studies, through improved estimates of burned biomass and atmospheric emissions (Li et al., 2019).
- Validation and complementarity with polar-orbiting products, where geostationary data provide temporal detail and polar sensors provide finer spatial detail (Vanunu et al., 2026).

Thus, geostationary satellites like EUMETSAT's Meteosat series are vital for wildfire monitoring, providing frequent, near-real-time thermal imaging for rapid detection, tracking, and early warnings. The Meteosat Third Generation (MTG) satellite system improves on the previous with higher-resolution, more sensitive thermal bands, enhancing risk assessment and emergency response (Xu et al., 2026).

A key product of the Land Surface Analysis Satellite Applications Facility (LSA-SAF) is the Fire Radiative Power (FRP-PIXEL), which estimates the location, timing, and radiative energy of active fires per pixel, serving as a proxy for fire intensity and biomass consumption. FRP-PIXEL is typically updated within minutes and can be combined with MTG imagery to visualize hotspots in context.

Despite their value, FRP products derived from geostationary products have important limitations such as coarser spatial resolutions and large range in view angles (from 0° at nadir to 70° + off-nadir) (Pestana & Lundquist, 2022). Spatial resolutions are of the order of kilometres, increasing from the satellite sub-point. Although most of detected fires are considerable smaller than a pixel, the minimum detected fire intensity scales with pixel size (Xu et al., 2026). As such, small or low-intensity fires are often missed by the relatively spatially coarse geostationary observations. Pixel size increases toward the edge of the satellite disk, as does atmospheric path length: together, these effects contribute to reduce sensitivity to smaller and low intense fires, introducing a bias towards large FRP retrievals for very large viewing angles.

1.1 The parallax effect

When satellites observations deviated from nadir, the apparent location of features such as mountains, clouds, or lightning can be shifted from its true ground position. This effect is known as parallax displacement. For geostationary observations, where viewing angles increase with increased distance from its sub-satellite point, the higher the object (feature) is above the ground, the larger will be the parallax shift (Liu et al., 2024; Vanu et al., 2026; Wiltink et al., 2025).

Although MTG's Flexible Combined Imager (FCI) optimizes hot-target detection and improves spatial and temporal continuity, the so-called Level-1C images have a standard projection that uses a smooth ellipsoid model of the Earth (WGS 84) (Mueller et al., 2018), which ignores mountains, valleys, and oceans, treating the Earth as a smooth, featureless surface, and assuming features are at sea level. So, when detected fires are located in elevated terrain, coordinates can be off (parallax displacement) (Figure 1).

1.2 Objectives

This study presents the new LSA-SAF MTG-derived FRP-pixel product, where the identified issue has been addressed by providing both FRP raw and the terrain corrected coordinates, so fire locations could be more correctly identified from space. Ongoing validation by the user community is still essential to ensure reliability and optimize its use in operational fire monitoring.

2. Data

This study uses the MTG Fire Radiative Power - MTG FRP-PIXEL (MTFRPPIXEL [LSA-509]) product derived from FCI/MTG observations produced by the EUMESAT LSA-SAF (<https://lsa-saf.eumetsat.int/en/data/products/fire-products/>). FRP-PIXEL from FCI/MTG is typically updated within minutes and can be combined with MTG imagery to visualize hotspots in context. The product is currently provided in demonstration mode, and has the following characteristics:

- Spatial resolution of 1km;
- Temporal resolution of 10 minutes;
- Available from 2025 to present, generated in near-real time (NRT).

The product consists of two distinct data components: a CSV-formatted FRP-PIXEL List Product, and a NetCDF4-formatted FRP-PIXEL Quality Product. The List Product records per-pixel variables for each detected active fire pixel, encompassing

temporal detection parameters, geographic coordinates (longitude and latitude), fire radiative power (FRP), and additional attributes. The Quality Product contains a two-dimensional array of quality flags that characterizes the processing status of all pixels within the imaging grid, including both fire-affected and non-fire pixels (e.g., water bodies, cloud-contaminated areas, sun-glint-affected regions, cloud-free areas without fire activity, and confirmed active-fire pixels). The FRP-PIXEL product structure and access details are available at the LSA-SAF website (<http://landsaf.ipma.pt>).

3. Methods

This product estimates the location, timing, and radiative energy of active fires per pixel, serving as a proxy for fire intensity and biomass consumption.

3.1 Parallax correction

The parallax shift caused by terrain elevation was corrected using Satpy's *ParallaxCorrection* class. Satpy (<https://satpy.readthedocs.io/en/stable/>) is an open-access Python library for processing and manipulating meteorological remote sensing data.

The correction procedure incorporated:

- the original pixel coordinates of each FRP detected point (in latitudinal and longitudinal degrees) to compute the terrain-adjusted locations position;
- a digital elevation model (DEM) at the native FCI resolution (1 km at nadir). The DEM used is the USGS Digital Elevation - Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) (<http://doi.org/10.5066/F7J38R2N>), available at 30-, 15-, and 7.5-arc-second spatial resolutions, and resampled to 1km resolution and for the same FCI/MTG spatial grid.
- the satellite's position (lat = 0°, lon = 0°);
- the orbital altitude (~35 786 km);

3.2 Validation

Due to the limited availability of field data on forest fires for the year 2025 onward (availability of the MTG FRP product), preliminary validation of the MTG FRP-pixel product was conducted through visual comparison with concurrent Sentinel-2 (S2) imagery.

S2 is a polar-orbiting satellite mission within the European Union's Copernicus Earth observation programme. The mission comprises twin satellites, carrying the Multispectral Instrument (MSI), which acquires optical imagery in 13 spectral bands from the visible and near-infrared to the shortwave infrared regions of the electromagnetic spectrum. Depending on the spectral band, MSI data are provided at spatial resolutions of 10 m, 20 m and 60 m, allowing detailed characterisation of land surface conditions. In this study, Sentinel-2 Level-2A products were used. These products provide atmospherically corrected and orthorectified Surface Reflectance, also referred to as Bottom-of-Atmosphere reflectance, and are therefore suitable for direct quantitative analysis. The images were downloaded from the Copernicus Data Space Ecosystem (<https://dataspace.copernicus.eu/>).

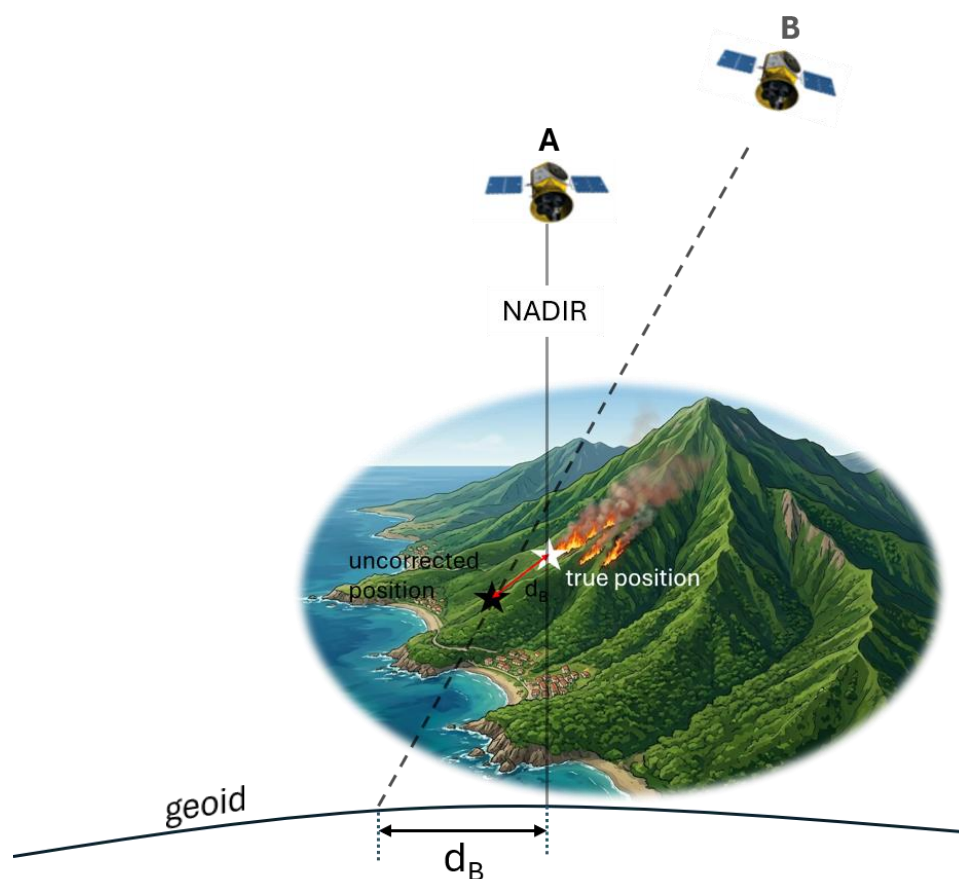


Figure 1. Schema illustrating the terrain-induced parallax effect. A – polar-orbiting satellite, B – geostationary satellite. Cartoon image of mountain fires was generated by AI (Gemini).

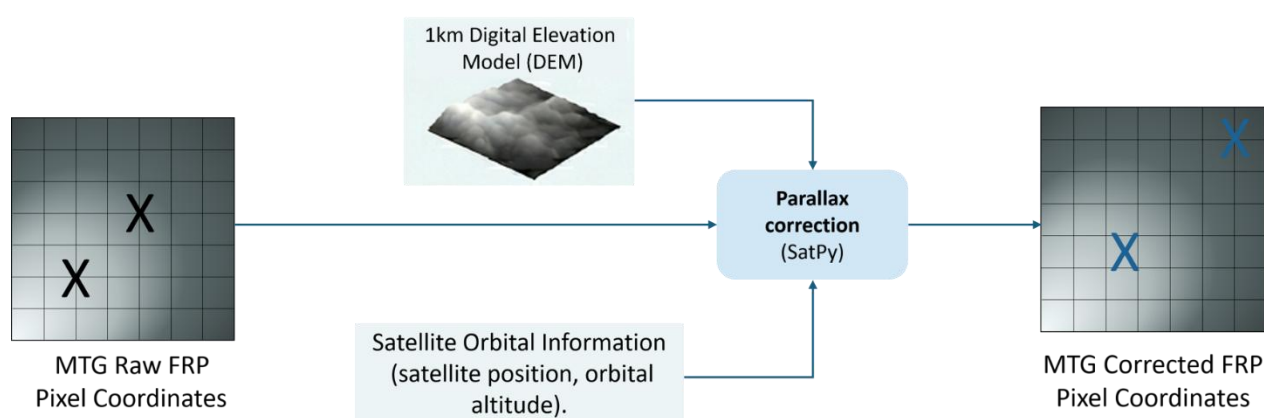


Figure 2. Flowchart of the procedure for correcting the terrain-induced parallax effect.

Detected original and terrain corrected FRP-pixel locations were overlaid with the Sentinel-2 images where fires were visible to assess the spatial correspondence between active fire detections and burned or actively burning areas.

This approach allowed initial evaluation of the detection accuracy, spatial alignment, and potential discrepancies, providing a first-level quality check prior to more comprehensive

validation with in-situ measurements or additional satellite products.

3.3 Application to a case study

The year 2025, particularly the months of July and August, were extremely prone to wildfires in Europe.

Portugal and Albania recorded extensive fires activity: Portugal - 200 fires and 278 917 ha of burned area; Albania – 132 fires and 59 933 ha of burned area (<https://forest-fire.emergency.copernicus.eu/apps/effis.statistics/estimates/PRT>).

To assess the efficacy of the parallax correction, the comparison of differences in spatial location between the original and terrain corrected FRP-pixel values was made for Portuguese and Albanian wildfires.

3.3.1 Portugal

July 30 of 2025 was particularly severe, as multiple fires were occurring. Nevertheless, this day provided availability of cloud free images from both MTG and S2 satellites while fires were active at different locations. The Sentinel 2 image was taken at 2025-07-30 T11:33:19, just 4 minutes apart from the FRP-PIXEL product (see Figure 3).



Figure 3. Credit: European Union, Copernicus Sentinel-2 imagery, image available at <https://www.copernicus.eu/pt-pt/node/94435>.

and the MTG FCI image at 2025-07-30 T11:37:44, allowing to compare the original and the terrain corrected FRP Pixel locations.

3.3.2 Albania

In mid-July 2025, the Albanian Ministry of Defence reported 18 wildfire outbreaks, threatening residential areas and environmentally protected zones (<https://eu-space.europa.eu/components/earth-observation-copernicus/image-of-the-day/albania-affected-devastating-wildfires>). The Lura National Park, in north-eastern Albania was among the areas most affected by the fires. The S2 image acquired in 2025-07-21 T09:30:51 clearly shows an active fire burning in this location. The MTG FCI FRP-PIXEL product, just 1 minutes apart, allowing to compare the original and the terrain corrected locations with the S2 ground-truth.

4. Results

Figure 4 shows the magnitude of the effect of parallax displacement as a function of terrain elevation and viewing angle over the European domain. The displacement between original and parallax-corrected FRP-pixel locations increases with terrain elevation (and with distance from the satellite viewpoint). This is clearly visible in high terrains like the Alps, and the Scandinavian fjords. In such areas, the estimated differences can be more than 3000 m.

Figure 5 depicts the FRP-PIXEL information for a low altitude (~100m). This fire also shows a complex fire perimeter. Figure 6 and 7, show FRP-PIXEL information for high-elevation terrains, ~800m and ~2000m respectively.

For fires occurring in high-elevation terrain (Figures 6 and 7) the correction improves the estimated fire location by approximately 700 m in the first case by about 2200m in last case.;

For low-elevation areas, or in cases where FRP detections are replicated due to algorithmic constraints, the correction yields limited improvement in spatial accuracy (Figure 5).

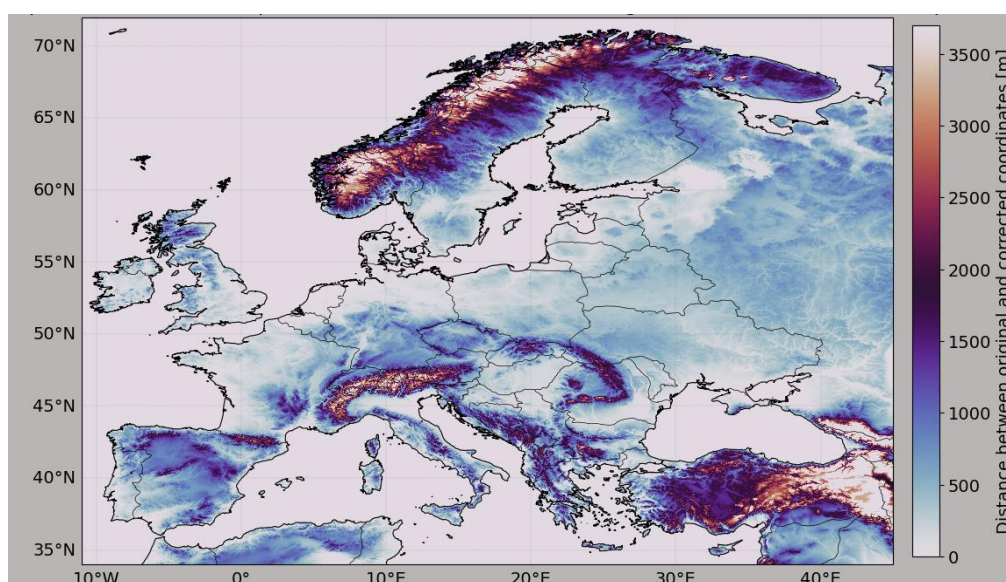


Figure 4. Spatial difference of the parallax correction for the MTG (nadir longitude = 0°) – Zoom over Europe

5. Discussion

The results of this study show that the magnitude of the parallax displacement is strongly controlled by both terrain elevation and viewing geometry.

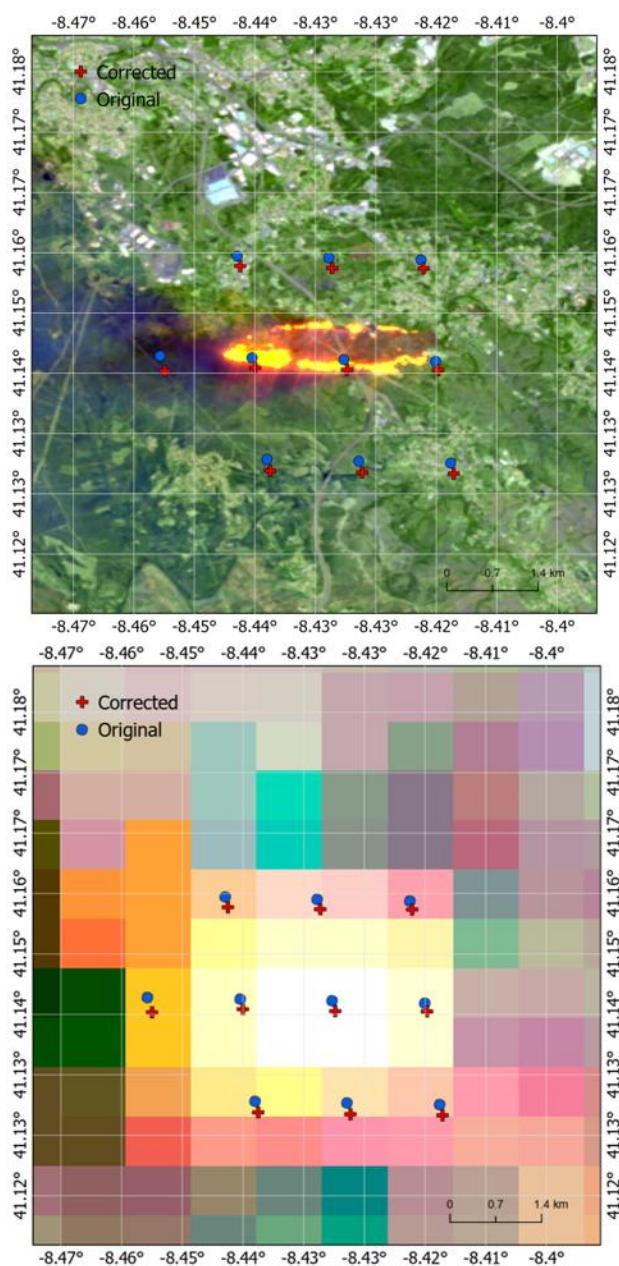


Figure 5 - Example for an active fire at ~100m altitude in Portugal: MTG FRP-PIXEL original LAT/LON pixel-centre coordinates (o) and corrected coordinates for the parallax effect of terrain height (+). Background: upper image - Sentinel-2 RGB composite acquired on 2025-07-30 T11:33:19; bottom image - MTG FCI image at 2025-07-30 T11:37:44.

As illustrated in Figure 4, the displacement between the original and parallax-corrected FRP-pixel locations increases with elevation and with distance from the satellite viewing point. This pattern is particularly evident over high-relief regions of the European domain, where estimated displacements can exceed 3000 m, and, in such cases, beyond the inherent uncertainty in fire location, i.e., about half the pixel's width, as most detected events cover only part of a pixel. These results confirm that

parallax effects are not spatially uniform and their correction is especially relevant for geostationary/moderate-to-high viewing angle observations over mountainous terrain.

The case studies further highlight the dependence of the correction impact on local topography. For the low-altitude fire shown in Figure 5, occurring at approximately 100 m elevation, the parallax correction produced only limited improvement in the estimated FRP-pixel location. This is expected, since parallax displacement is relatively small over low-elevation terrain. In addition, the presence of replicated FRP detections, associated with algorithmic constraints in the FRP-PIXEL product (Figure 5 – bottom), can limit the apparent benefit of the correction because multiple detections may represent the same fire feature or may not correspond precisely to independent active-fire locations.

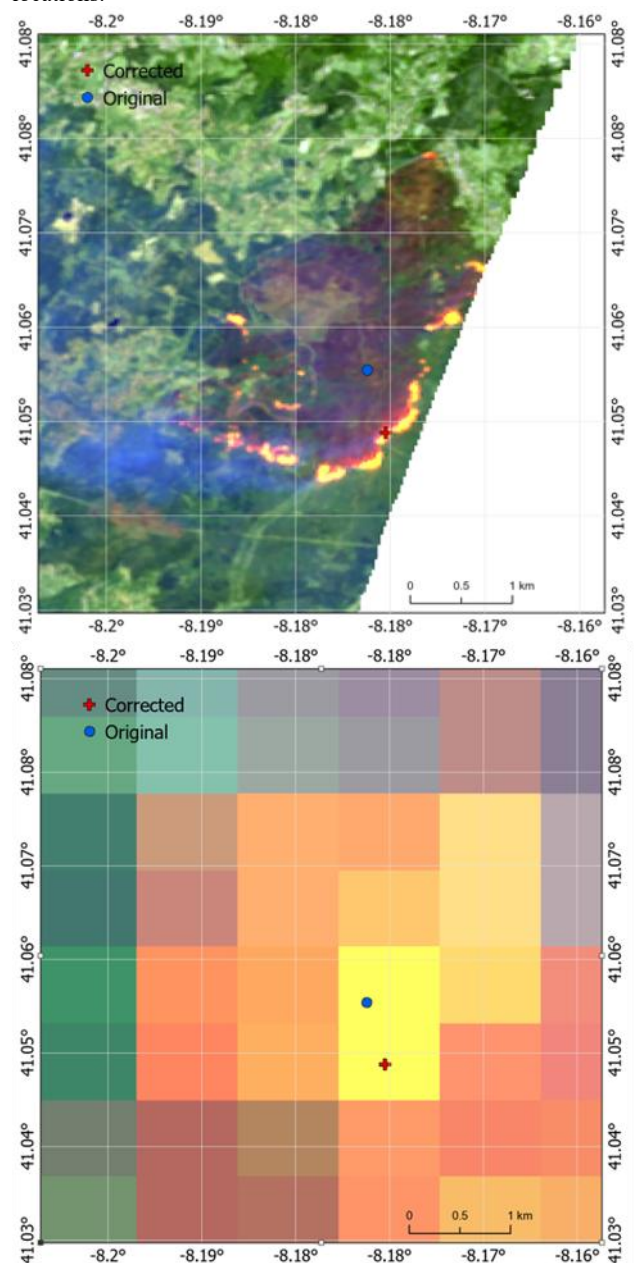


Figure 6 - Example for an active fire at ~800m altitude in Portugal: MTG FRP-PIXEL original LAT/LON pixel-centre coordinates (o) and corrected coordinates for the parallax effect of terrain height (+). Background: upper image - Sentinel-2 RGB composite acquired on 2025-07-30 T11:33:19; bottom image - MTG FCI image at 2025-07-30 T11:37:44.

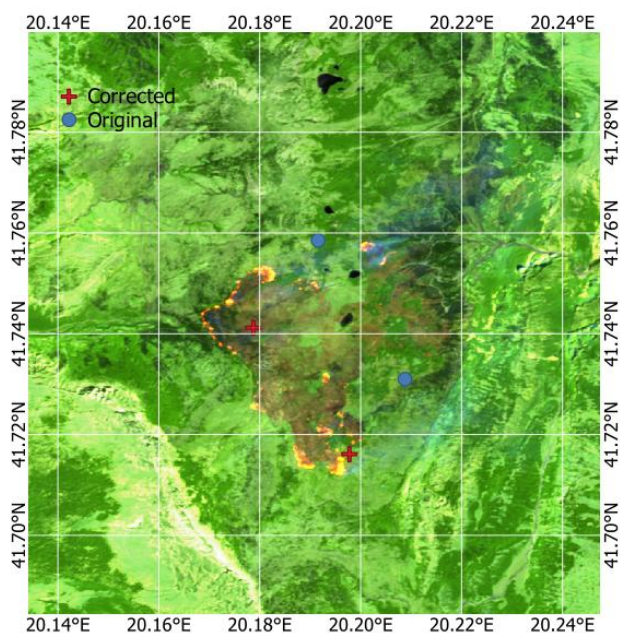


Figure 7 - Example for an active fire at ~2000m altitude in Albania: MTG FRP-PIXEL original LAT/LON pixel-centre coordinates (o) and corrected coordinates for the parallax effect of terrain height (+). Background image: Sentinel-2 RGB composite acquired on 2025-07-21 T09:30:51.

By contrast, the fires located at higher-elevation terrains show a clearer spatial improvement after correction. These two examples demonstrate that the implemented correction can substantially reduce terrain-induced geolocation errors in mountainous regions, where the original FRP-pixel coordinates may otherwise be displaced by distances comparable to, or greater than, the nominal spatial resolution of the FCI/MTG imagery.

Although the correction represents an important step towards improving the geolocation accuracy of geostationary FRP observations, its effectiveness is conditioned by terrain complexity, viewing geometry, DEM resolution and the characteristics of the FRP detection algorithm.

The parallax correction procedure implemented in this study used a DEM downsampled to the 1 km spatial resolution of the original FCI/MTG imagery from which the FRP-Pixel product is derived. This choice ensures spatial consistency between the elevation data and the satellite observations used for FRP estimation. However, it also represents a potential limitation, particularly in areas of steep or heterogeneous terrain, where sub-pixel elevation variability may not be fully captured. As a result, residual geolocation errors may remain after correction, especially where the true fire location lies on slopes, ridges, valleys or other terrain features that are smoothed by the resampled DEM.

The comparisons between uncorrected and corrected coordinates were performed using active-fire locations derived from satellite imagery. Although this provides a useful first assessment of the geometric impact of the correction, a more comprehensive validation would require independent reference data. Future work could include the evaluation of corrected FRP-PIXEL locations against high-resolution burned area perimeters, active-fire lines, fire progression maps and in situ observations (Liu et al., 2024). This would allow a more robust assessment of whether the spatial displacement correction improves the physical representation of fire location and dynamics.

Such validation would be especially valuable for complex fire events, where the relationship between the FRP-pixel centroid and the actual burning front may be non-trivial. Because FRP pixels represent sub-pixel thermal activity within a relatively

coarse geostationary pixel, the corrected coordinate should not necessarily be interpreted as the exact location of the fire front. Rather, it should be understood as an improved estimate of the geolocation of the fire-affected pixel, subject to uncertainties related to sensor resolution, detection thresholds, terrain representation and fire heterogeneity within the pixel. Consequently, the parallax correction improves the geometric consistency of the product, but it does not eliminate all sources of spatial uncertainty inherent to geostationary active-fire observations.

6. Conclusions

In conclusion, the parallax correction improves the geolocation of FRP-Pixel detections, particularly over high-elevation and complex terrain where displacement can reach several kilometres. The results show limited impact in low-altitude areas. However, there is still the need to use in situ data to further assess the usefulness of the correction for the FRP-PIXEL users community. Overall, the correction represents an important step towards improving the spatial accuracy of geostationary FRP products, especially in mountainous regions.

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